Fauna by-catch in pipeline trenches: conservation, animal ethics, and current practices in Australia

J. Sean Doody[1,2], Peter West[1], Jessica Stapley[1], Michael Welsh[1], Anton Tucker[1,2], Enzo Guarino[1,2], Matthew Pauza[1], Nina Bishop[1], Megan Head[1], Stuart Dennis[1], Geoff West[1], Ashe Pepper[1], and Amanda Jones[1]

[1]Ecos Consulting (Aust) Pty Ltd, Suite 4, Level 1, 443 Little Collins Street, Melbourne, VIC 3000

[2]Present address: Applied Ecology Research Group, University of Canberra, ACT 2601,
email: doody@aerg.canberra.edu.au

ABSTRACT

We use the Eastern Gas Pipeline (EGP) in southeastern Australia as a case study to examine the value of documenting and retrieving entrapped fauna from open pipeline trenches. Daily inspection of nearly 800 km of open pipeline trenches during construction of the EGP (1999-2000) resulted in the identification of 103 vertebrate species (45 reptiles, 24 mammals, 19 frogs, 14 birds, 1 fish). Of 7438 individuals found in the open trenches, 7125 (97%) were found alive and released. Of the 224 dead animals, 29 (13 %) were of two threatened mammal species, most of which drowned in low flooded sections of trenches following rainfall. Nine threatened species were found in trenches, and an additional 5 threatened species were found along the pipeline route. Importantly, most threatened species were found outside of protected areas. Our findings indicate that wildlife conservation should play an important role in pipeline construction, but more emphasis should also be placed within the broader arena of animal ethics, or the retrieval and release of unlisted species. Despite preventative measures taken to minimise mortality in trenches (e.g., ramped earth known as 'trench plugs' positioned every 500 m to allow entrapped animals to escape), smaller (< 75 g), less-mobile animals were unlikely to survive, unless retrieved. There is no current legislation governing the rescue of fauna from trenches during pipeline construction, despite the current increase in pipelines in Australia, although the measure is included as a recommendation in the Australian Pipeline Environmental Code of Practice. Our data indicate that retrieving trench fauna solely within protected areas or sensitive areas (e.g., national parks, nature reserves, selected areas of native vegetation or wetlands), as is sometimes currently practised, will not protect all, or even most, threatened species. Retrieving fauna from the entire trench as standard practice during pipeline construction would be beneficial to native fauna, and therefore to conservation bodies, industry, and the general community.

Key words: fauna, surveys, pipeline construction, threatened species, animal ethics

Introduction

Clearing of vegetation is generally detrimental to the diversity of native fauna (Dobson *et al.* 1997). Yet, as the human population expands so does the pressure for clearing or altering landscapes. A major problem in balancing the needs of human expansion and environmental integrity is an inadequate knowledge of fauna distributions at scales appropriate for predicting impacts of development on conservation of species, communities, and ecosystems. One solution to reduce this deficiency is to survey for fauna prior to or during development. Such information provides baseline inventories that are essential for understanding species assemblages at a range of spatial scales. However, the enormous costs associated with field surveys are obstacles to collecting data on fauna distributions and abundance (Burbidge 1991).

A unique opportunity exists to build such fauna inventories by sampling open trenches for fauna during pipeline construction (Ayers and Wallace 1997; Woinarski *et al.* 2000). Pipeline trenches are excavated by specialised machinery and remain open for days to weeks until pipes are welded and lowered into the trench and covered with soil. Open trenches serve as an extensive pitfall trap (Ayers and Wallace 1997); fauna from surrounding habitats inadvertently fall into the trench and are often unable to escape. Pipeline trenches offer a unique survey method – providing fine-scale sampling over a great distance. Conventional pitfall sampling at the large scale typical of a pipeline trench (e.g., hundreds of kilometers) would incur prohibitively high costs, and would bias captures with respect to animal taxa (Woinarski *et al.* 2000). In contrast, the retrieval of fauna from already excavated pipeline trenches requires comparatively little additional expenditure (labour costs associated with walking along the trenches searching for trapped fauna), and pipeline trenches are less biased (Woinarski *et al.* 2000).

Herein we use the Eastern Gas Pipeline (EGP) in southeastern Australia as a case study to examine the value of documenting and retrieving entrapped fauna from open pipeline trenches. We surveyed nearly 800 km of open trenches daily throughout construction, identifying, rehabilitating, and releasing captured vertebrates. We compare our findings to those of other pipeline fauna surveys, and discuss implications for conservation and animal ethics. We also examine current practices of fauna retrieval in Australia.

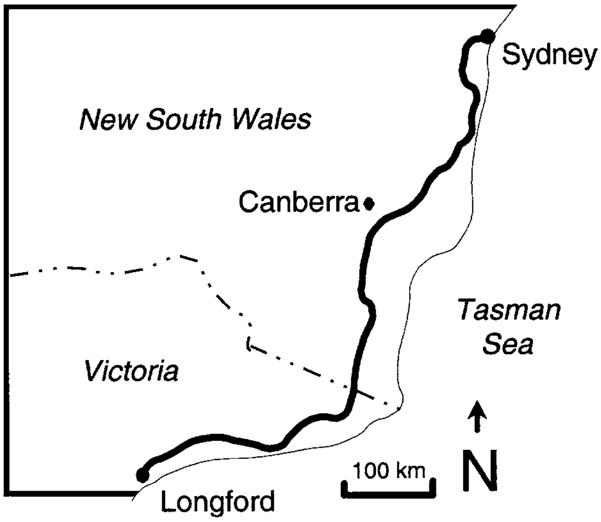

Figure 1. Route of the Eastern Gas Pipeline.

Materials and methods

The Eastern Gas Pipeline (EGP) was constructed in 1999-2000 to transport natural gas from Longford, Victoria to Horsely Park west of Sydney, New South Wales (Fig. 1). The pipeline is 792 km in length, and a 20 m wide easement was cleared to facilitate installation, except in highly-sensitive areas, where the easement was reduced (Duke Eastern Gas Pipeline 1999). The pipeline route crossed a wide variety of habitats, including wet sclerophyll forests and heathlands, dry woodland, native grasslands, and improved pastures.

The pipeline was constructed by four widely-spaced crews (construction spreads) working simultaneously. The trenches were excavated using wheel ditchers and excavators, and pipes were welded and lowered into open trenches, which were then back-filled with soil. Sections of trench remained open for days to weeks depending on a variety of factors (e.g., weather), and were generally restricted to 15 km in length. Trenches were sheer-walled, 90 cm wide and 1-3 m deep (averaging 1.5 m).

Originally, fauna retrieval was to occur only in 'fauna management' areas, or 'sensitive areas' (e.g., Morton National Park) identified by New South Wales National Parks and Wildlife Service (NSWNPWS) and Department of Natural Resources and Environment Victoria (DNRE), prior to construction. However, the finding of large numbers of fauna in open trenches early in the construction phase prompted an expansion of fauna retrieval to all open trenches. This practice was volunteered by the proponent (initially West Coast Energy/BHP but sold to Duke Energy International), rather than imposed.

A team of 2-4 persons surveyed open trenches daily on each construction spread, with each person covering ca. 3-8 km per day. Most surveys began in late morning and ended by 1600-1700 hrs. This schedule was chosen to maximise overlap between surveys and activity of ectothermic animals, which often go undetected under soil lumps and rocks while inactive (pers. obs.). Surveys involved walking alongside the open trench searching for animals, and retrieving them with a long-handled dipnet (modified from a pool net). Due to the risk of trench collapse while working in a confined space, project safety requirements prohibited entry into the trench for all personnel. However, we were permitted to enter the trench briefly (and under supervision) to retrieve animals that could not be removed with dipnets. Some venomous snakes were retrieved with specialised tongs (Fig. 2).

Identification of animals to species was facilitated by appropriate texts (Strahan 1998; Simpson and Day 1999; Cogger 2000). Retrieved animals were usually released immediately upon identification in habitat adjacent to the easement near where they were found. Occasionally animals were taken out of the field for rehabilitation (i.e., wet, hypothermic mammals) or when in need of further inspection for identification. A few mammals were taken to state wildlife rescue and rehabilitation units (e.g. WIRES) for rehabilitation. Dead specimens of species of interest were preserved and deposited into museum collections.

After discovering that many frogs and possibly other small animals were hiding under soil and debris in the trench, and thus going undetected, we employed funnel traps opportunistically into the trench in East Gippsland. Funnel traps were constructed of hardware wire (0.5 cm mesh) and were ca. 1 m long, consisting of a 30 cm diameter cylinder and wire funnels on each end (see Heyer *et al.* 1994). Funnels were made to span the entire trench width such that animals that were small enough to fit into the funnels (ca. 7 cm diam.) were trapped as they moved along the trench bottom. A string tied to traps allowed them to be checked without personnel entering the trench. Traps were checked in the morning to prevent desiccation and over-exposure.

Figure 2. An eastern brown snake *Pseudonaja textilis* captured in the open trench near Captains Flat, NSW by E. Guarino. Photograph by S. Doody.

Table 1. Vertebrates retrieved from open trenches during construction of the EGP in 1999-2000. Members of two species groups of frogs (*Litoria ewingii/verreauxii; Pseudophryne bibroni/dendyi*) were not identified to species.

Group and scientific name	Common name	Abundance
Reptiles		
Lizards		
Agamidae		
Amphibilorus muricatus	Jacky Lizard	135
Pogona barbata	Eastern Bearded Dragon	1
Tympanocryptis diemensis	Mountain Dragon	151
Gekkonidae		
Oedura leseuerii	Lesueur's Velvet Gecko	2
Phyllurus platurus	Broadtail Gecko	2
Pygopodidae		
Pygopus lepidopodus	Common Scalyfoot	4
Scincidae		
Bassiana duperreyi	Three-lined Skink	10
Bassiana platynota	Red-throated Skink	11
Cryptoblepharus virgatus	Wall Lizard	2
Ctenotus taeniolatus	Copper-tailed Skink	29
Ctenotus uber	Spotted-back Skink	2
Cyclodomorphus michaeli	She-oak Skink	9
Egernia cunninghami	Cunningham's Skink	4
Egernia saxatilis	Black Rock Skink	17
Egernia whitii	White's Skink	4
Eulamprus heatwolei	Heatwole's Water Skink	31
Eulamprus quoyii	Eastern Water Skink	13
Eulamprus tenuis	Barred-sided Skink	2
Eulamprus tympanum	Southern Water Skink	160
Hemiergis decresiensis	Three-toed Skink	13
Lampropholis delicata	Grass Skink	363
Lampropholis guichenoti	Garden Skink	699
Nannoscincus maccoyi	Maccoy's Skink	334
Niveoscincus conventryi	Litter Skink	418
Pseudemoia entrecasteauxi	Mountain Log Skink	142
Pseudemoia pagenstechneri	Tussock Skink	17
Pseudemoia rawlinsoni	Bog Skink	3
Pseudemoia spenceri	Spencer's Skink	15
Saproscincus mustelinus	Weasel Skink	56
Tiliqua nigrolutea	Blotched Blue-tongued Lizard	42
Tiliqua scincoides	Common Blue-tongued Lizard	10
Varanidae		
Varanus rosenbergi	Rosenberg's Monitor	2
Varanus varius	Lace Monitor	7
Snakes		
Elapidae		

Group and scientific name	Common name	Abundance
Austrelaps ramsayi	Highland Copperhead	35
Cacophis squamulosus	Golden Crowned Snake	2
Demansia psammnophis	Yellow-faced Whipsnake	1
Drysdalia coronoides	White-lipped Snake	38
Drysdalia rhodogaster	Blue Mountains Crowned Snake	3
Hoplocephalus bungaroides	Broad-headed Snake	1
Notechis scutatus	Tiger Snake	9
Pseudechis porphryiacus	Red-bellied Blacksnake	27
Pseudonaja textilis	Eastern Brown Snake	7
Rhinoplocephalus nigrescens	Eastern Small-eyed Snake	6
Suta flagellum	Little Whip Snake	1
Turtles		
Chelidae		
Chelodina longicollis	Long-necked turtle	20
Frogs		
Hylidae		
Litoria aurea	Green and Golden Bell Frog	19
Litoria citropa	Blue Mountains Tree Frog	436
Litoria dentata	Bleating tree frog	129
Litoria ewingii/verreauxii	Brown/Whistling Tree Frog	44
Litoria lesueurii	Lesueur's Frog	699
Litoria littlejohni	Heath frog	3
Litoria peronii	Peron's Tree Frog	30
Litoria nudidigitis	Southern Leaf Green Tree Frog	18
Litoria tyleri	Tyler's Tree Frog	2
Myobatrachidae		
Crinia parainsignifera	Eastern Sign-bearing Froglet	9
Crinia signifera	Common Eastern Froglet	1161
Geocrinia victoriana	Eastern Smooth Frog	20
Limnodynastes dumerelli	Eastern Banjo Frog	110
Limnodynastes peronii	Brown-striped Frog	278
Limnodynastes tasmaniensis	Spotted Grass Frog	988
Neobatrachus sudelli	Sudell's Frog	3
Paracrinia haswelli	Haswell's Frog	17
Pseudophryne bibroni/dendyi	Brown Toadlet/Southern Toadlet	135
Uperolia laevigata	Smooth Toadlet	2
Mammals		
Acrobatidae		
Acrobates pygmaeus	Feathertail Glider	12
Bovidae		
Bos taurus	Cattle	7
Ovis aries	Sheep	1
Burramyidae		
Cercartetus nanus	Eastern Pygmy Possum	64

Canidae		
Canis lupus	Dog/Dingo	1
Dasyuridae		
Antechinus agilis	Agile Antechinus	15
Antechinus stuarti	Brown Antechinus	31
Antechinus swainsonii	Dusky Antechinus	30
Sminthopsis murina	Common Dunnart	2
Felidae		
Felis catus	Feral Cat	3
Leporidae		
Oryctolagus cuniculus	European Rabbit	8
Macropodidae		
Macropus giganteus	Eastern Grey Kangaroo	11
Wallabia bicolor	Black Wallaby	2
Muridae		
Mus musculus	House Mouse	24
Rattus fuscipes	Bush Rat	5
Rattus lutreolus	Swamp Rat	2
Rattus rattus	Black Rat	3
Peramelidae		
Perameles nasuta	Long-nosed Bandicoot	9
Petauridae		
Petaurus breviceps	Sugar Glider	1
Potoroidae		
Potorous longipes	Long-footed Potoroo	1
Pseudocheiridae		
Pseudocheirus peregrinus	Common Ringtail Possum	4
Tachyglossidae		
Tachyglossus aculeatus	Echidna	9
Vombatidae		
Vombatus ursinus	Common Wombat	1
Microchiroptera spp.	unidentified bat spp.	2
Birds		
Anatidae		
Anas platyrynchos	Mallard	1
Anas superciliosa	Pacific Black Duck	1
Chenonetta jubata	Wood Duck	1
Alaudidae		
Mirafra javanica	Singing Bushlark	2
Artamidae		
Strepera graculina	Pied Currawong	1
Cacatuidae		
Calyptorhynchus funereus	Yellow-tailed Black Cockatoo	6
Dicruridae		
Rhipidura leucophrys	Willie Wagtail	2

Group and scientific name	Common name	Abundance
Hirundinidae		
Hirundo neoxena	Welcome Swallow	1
Maluridae		
Malurus cyaneus	Superb Fairy Wren	2
Menuridae		
Menura novaehollandiae	Superb Lyrebird	2
Motacillidae		
Anthus novaeseelandiae	Richard's Pipit	9
Phasianidae		
Coturnix chinensis	King Quail	1
Coturnix ypsilophora	Brown Quail	1
Strigidae		
Ninox novaeseelandiae	Southern Boobook	1
Fish		
Anguillidae		
Anguilla australis	Short-finned Eel	1

Results

Diversity of trench captures

We retrieved 103 vertebrate species from open trenches during construction of the EGP (Table 1). Most entrapped species were reptiles (45 species = 44 %), followed by mammals (24 = 23 %), frogs (19 = 18 %), birds (14 = 14 %), and fish (1 = 1 %). Most species retrieved from the trench were natives, and most were small in body size (< 75 g). Most large animals temporarily trapped in the trench escaped via ramped earth positioned every 500 m, as evidenced by footprints at these locations (pers. obs.). Exceptions were a few large animals that became stuck in the mud in the trench bottom (e.g., wombats, wallabies, cattle).

A total of 7438 individual animals were retrieved from open trenches (Table 1). Frogs were the most abundant (4103 = 55 %), followed by reptiles (2960 = 40 %), mammals (254 = 3.5 %), birds (31 = 0.5 %), and fish (1 = < 0.1 %). Locality data for all captures, and for several thousand additional incidental records during pipeline construction, have been lodged with the state Atlas Databases of New South Wales (National Parks and Wildlife Service) and Victoria (Department of Natural Resources and Environment). Of the trench captures, 549 individuals were caught in funnel traps. Most of these were frogs (N = 541), but a few snakes (N = 5) and small mammals (N = 3) were captured.

Mortality

Of the total animals retrieved from the open trenches, 7125 (96 %) were found alive and 224 (4 %) dead. Of the dead animals found in the open trench, 112 (50 %) drowned. Most drowned animals were small mammals (N = 106; 95 %).

Threatened species

Fourteen state- and/or federally-listed species were found during fauna inspection of the EGP in both New South Wales and Victoria (Table 2). Nine of these species were found in open trenches, and most were reptiles (Table 2; Fig. 3). Of the 14 listed species, 12 were found in unprotected areas, while three were found within Morton National Park (although technically the pipeline easement followed the road alignment) and three were found in Kuma Nature Reserve (Table 2). The most commonly entrapped threatened species was the eastern pygmy possum, *Cercartetus nanus* (N = 60 in NSW). One specimen of a federally-threatened species, the long-footed potoroo (*Potorous longipes*), was found in East Gippsland near Bellbird Creek. This species had not been recorded south of the Princes Highway in over 10 years (S. Henry, Department of Natural Resources and Environment, pers. comm.). Another noteworthy find was a specimen of the threatened little whipsnake (*Suta flagellum*) from near Bredbo, NSW. This specimen filled a hiatus between previously known populations north of Canberra and Cooma (W. Smith, NSWNPWS, pers. comm.).

Reptiles

Most reptiles entrapped in the trench were lizards (5 families, 20 genera, 33 species), and the majority of these were small skinks (Scincidae, 25 species) (Table 1). High skink species richness was found in East Gippsland (Vic), south of Nowra (NSW), and northwest of Wollongong (NSW). Each of these areas produced > 10 species of skinks. The greatest density of skinks was found in forested areas of East Gippsland, where we removed > 300 skinks in a single day in < 5 km of trench. Other lizards caught in the trench were three species of dragons (Agamidae), and two species each of goannas (Varanidae; Fig. 3), geckos (Geckonidae), and a legless lizard (Pygopodidae).

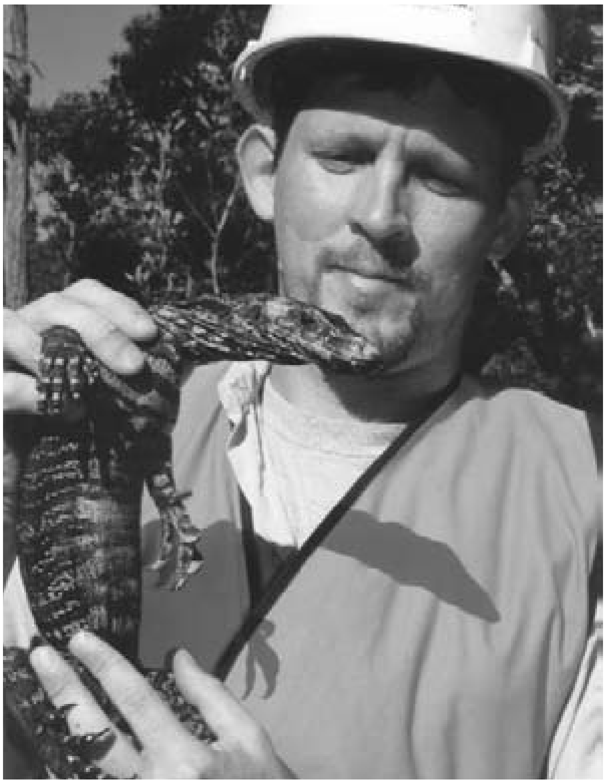

Figure 3. A lace monitor *Varanus varius* captured in the open trench in East Gippsland, Vic. by S. Doody. Photograph by N. Bishop.

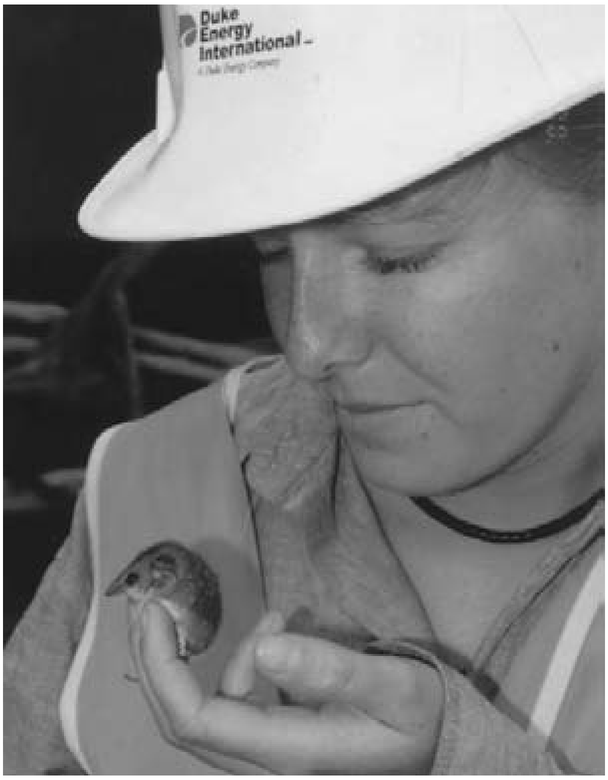

Figure 4. A common dunnart *Sminthopsis murinus*, captured in the open trench near Nowra, NSW by N. Bishop. Photograph by S. Doody.

Table 2. Listed fauna species found during construction of the EGP in 1999-2000. For listings, AUS = Environment Protection and Biodiversity Conservation Act (1999), NSW = NSW Threatened Species Conservation Act (1995), Vic = Flora and Fauna Guarantee Act (1988). For location, T = trench, R = pipeline route prior to construction, A = adjacent habitat. For designation, P = national park, R = nature reserve, U = unprotected area. Adundance data reflect only captures within the listed state (see listing column).

Species	listing	abundance	location	designation
Mammals				
Potorous longipes	Endangered (AUS), Endangered (NSW)	1	T	U
Cercartetus nanus	Vulnerable (NSW)	60	T	U, P
Reptiles				
Hoplocephalus bungaroides	Endangered (NSW)	1	T	U
Suta flagellum	Vulnerable (NSW)	4	T, R	U, R
Tympanocryptis lineata				
Pinguicolla check	Endangered (NSW)	9	R, A	R
Delma impar	Vulnerable (NSW)	28	R, A	U, R
Varanus rosenbergi	Vulnerable (NSW)	6	T, R, A	U, P
Cyclodomorphus michaeli	Near threatened (Vic)	1	T	U
Pseudemoia rawlinsoni	Near threatened (Vic)	3	T	U
Varanus varius	Data deficient (Vic)	3	A	U
Frogs				
Litoria aurea	Near Threatened (Vic)	19	T	U
Litoria littlejohni	Vulnerable (NSW)	3	T	P
Birds				
Ninox strenua	Endangered (Vic), Vulnerable (NSW)	1	A	U
Calyptorhynchus lathami	Vulnerable (NSW)	3	A	U

Snakes were the second most speciose reptile group found (1 family = Elapidae, 10 genera, 11 species; Fig. 2), followed by turtles (1 species, Chelidae). The most commonly entrapped reptile was the skink *Lampropholis guichenoti* (N = 699).

Mammals

Mammals were the second most speciose group recorded in the trenches (16 families, 20 genera, 24 species). Several exotic (cat, fox, rabbit, house mouse, black rat) and domesticated species (cattle, sheep) were seen in, or retrieved from, the trench (Table 1). Most entrapped native mammals were small (Dasyuridae = 4 species; Muridae = 4 species, Burramyidae, Petauridae, Acrobatidae = 1 species each) or medium-sized (Paramelidae, Pseudocheiridae, Potoroidae, Tachyglossidae, = 1 species each; Fig. 4). Large mammals (Macropodidae = 2 species; Vombatidae = 1 species) were uncommon, and were generally injured or stuck in mud. The most commonly entrapped native mammal was the eastern pygmy possum, *Cercartetus nanus* (N = 64). Most *C. nanus* were entrapped in and near Morton National Park, between the Endrick River and Nowra, NSW.

Frogs

Frogs entrapped in the trenches included 10 species of southern frogs (Myobatrachidae) and nine species of tree frogs (Hylidae). Hylid frogs were represented by several ecological groups including arboreal, terrestrial, and fossorial species, and included riverine and non-riverine species (Table 1). Particularly high abundances of frogs were found south of Nowra, NSW and in East Gippsland, Victoria. The most commonly entrapped frog was *Crinia signifera* (1161 individuals). Sections of trench that held water continuously for several days attracted amplexing (mating) frogs, and eggs and tadpoles of three species were found in the trench bottom (*Crinia signifera, C. parainsignifera, Limnodynastes tasmaniensis*).

Birds and fish

Trapped birds were relatively uncommon in the trenches (11 families, 12 genera, 14 species). Several of these animals were fledglings that could not yet fly. One predatory species, the southern boobook owl *Ninox novaeseelandiae* may have utilised the trench to find prey. Only one individual of one fish species, the short-finned eel *Anguilla australis*, was found in the trenches.

Other entrapment mitigation strategies

In some areas, trenches held water for extensive periods of time (i.e., days to 2 weeks), especially if wet conditions prevented continued construction. After finding drowned animals in these sections, a few other measures were taken in an attempt to reduce mortality rates. These included (1) pumping out water (carried out by construction personnel), (2) constructing drift (silt) fences along the top of trenches near flooded sections of trench, (3) employing funnel traps in the trench bottom at the water's edge, (4) positioning branches and other objects to serve as ladders from the pooled water to the top of trenches, (5) placing floating objects in the flooded sections, and (6) using makeshift 'bridges' across the trenches. Drift fences were placed between habitats and the trench to prevent animals from falling into flooded sections of the trench. Funnel traps (See Heyer *et al.* 1994) were employed to capture frogs, snakes, and small mammals on the trench bottom at the water's edge. Although our study was not designed to test the usefulness of these procedures, there was evidence that some of them were at least partly successful. For example, we placed dirt on makeshift bridges, on which we subsequently found animal tracks (wombat, bandicoot), and funnel traps were effective in capturing large numbers of frogs.

Discussion

Our study reinforces the value of retrieving trapped fauna from pipeline trenches (Ayers and Wallace 1997; Woinarski *et al.* 2000). First, we rescued several thousand vertebrate animals including several threatened species. In particular, we retrieved numerous small animals (frogs, lizards, small snakes, and small mammals) that were unable to escape due to their low mobility relative to the distance between trench plugs (ramped soil every 500 m). Second, a faunal inventory built during construction of the EGP provided valuable scientific data on the distribution and abundance of many species. The inventory, in amalgamation with other distributional data in state atlases, increases our understanding of spatial patterns of Australian vertebrate assemblages. For example, the finding of a specimen of the threatened little whipsnake *Suta flagellum* filled a hiatus in its known distribution, and two specimens of Tyler's tree frog *Litoria tyleri*, whose distribution is not well-known, were also found. Third, our data provide a further impetus to ensure that fauna retrieval during construction becomes standard practice in future pipelines. Lastly, the project developed methods novel to pipeline surveys that could be implemented in fauna monitoring on future pipelines.

Comparisons with other pipeline trench fauna surveys

Reptiles were the most speciose group in the EGP trench inventory, followed by mammals, frogs, birds, and fish. This pattern mirrors trench fauna captures recorded in three other Australian pipeline studies (Ayers and Wallace 1997; Faulkner, 1999; Woinarski *et al.* 2000). In terms of abundance, frogs dominated the EGP trench captures (followed by reptiles, mammals, birds, and fish), similar to the Marsden-Dubbo pipeline captures (Faulkner 1999). In the other two pipeline studies reptiles were the most abundant (followed by mammals, frogs, and birds). The higher abundance of frogs during the EGP likely reflects the pipeline's route through wetter habitats compared to the Moomba-Sydney and Daly Waters pipelines, but may also be related to differences in the amount of rainfall during their construction. The most abundant reptiles differed among pipeline studies, and were also likely related to site-specific differences in habitat and climate. Small skinks dominated the EGP inventory, the larger shingleback skink *Trachydosaurus rugosus* was most abundant in the Moomba-Sydney

Pipeline (Ayers and Wallace 1997), and legless lizards (Pygopodidae) dominated in the Daly Waters-McArthur Pipeline (Woinarski *et al.* 2000).

Mortality of entrapped fauna was low (3 %), particularly compared to studies quantifying mortality in pipelines without formalised fauna retrieval (41.8 %, Ayers and Wallace 1997; 52.5 %, Faulkner, 1999; 25 % in 1994 survey, 11 % in 1999 survey, Woinarski *et al.* 2000). The chief cause of mortality during the present study was drowning, usually when the trench crossed saturated depressions in forested areas. The most significant losses were the drownings of 28 entrapped eastern pygmy possums (*C. nanus*). These animals drowned in low, flooded sections of the trench after rainfall, despite our efforts to provide floats and 'ladders' in flooded areas. Some efforts were also made by construction crews to drain these sections of trench with pumps. A single specimen of the federally-threatened long-footed potoroo (*P. longipes*) was found dead of unknown causes (although a post-mortem revealed crush injuries around the chest, inconsistent with death due to falling in trench, S. Henry, DNRE, pers. comm.). Dehydration was a major cause of mortality (especially among frogs) in the Moomba-Sydney Pipeline study (Ayers and Wallace 1997). The lack of dehydration and desiccation in our study is probably due to our daily fauna retrieval and the relatively wetter, more humid, and cooler conditions along the EGP route compared to that of the Moomba-Sydney Pipeline.

Our extensive work on the EGP provides a useful comparison of fauna retrieval practices to those of previous studies. Previous studies have suggested that trench surveys should be conducted in early morning to reduce mortality (Ayers and Wallace 1997; Woinarski *et al.* 2000). We feel this is an oversimplification: although early morning checks will reduce the amount of time animals spend in the trenches, such procedures would increase the probability of overlooking small ectothermic animals. We found that in months with cool mornings, small ectotherms (mainly lizards and snakes) did not become active until mid- to late morning, when sunlight reached the trench bottom. Surveys initiated too early would not detect these animals, which hide under soil while inactive. Search method is also important, however. We were not allowed to walk in the trench due to workplace safety constraints, hindering efforts to locate small animals hiding under loose soil. Surveys associated with construction of some other pipelines have involved walking within the trenches (Ayers and Wallace 1997). It is worth noting that our estimate of entrapped animals (and thus, mortality rate) is likely to be conservative, given that some small animals hiding in trench spoil would have been overlooked. Finally, in contrast to the present study, fauna retrieval later in the morning at the Daly Waters pipeline would likely have resulted in higher mortality of entrapped mammals (J. Woinarski, pers. comm.), indicating that animal type should be considered in choosing an optimal time to retrieve fauna. In summary, our results and those of others demonstrate that the diel timing of trench surveys should consider daily temperature and irradiation (influenced by time of year), survey method, and the type of entrapped animals.

Implications for conservation, animal ethics, and future practices of fauna retrieval

Several threatened species were found in the trenches and along the pipeline route during construction of the EGP (Table 2). This list, which is dominated by small reptiles, highlights the need for continued consideration of threatened species conservation during pipeline construction (Ayers and Wallace 1997). With two notable exceptions, threatened species were found alive and were released, minimising the impact of construction activities on threatened species.

The majority of entrapped threatened species were in unprotected areas. This was likely a consequence of the high proportion of trench transecting those areas (i.e., < 5 % of the pipeline traversed protected lands such as national parks or nature reserves). Regardless of the reason, this finding has implications for future fauna retrieval practices: removing fauna only from 'sensitive areas' during pipeline construction will not necessarily protect all, or even most, threatened species. The current code of practice of the Australian Pipeline Industry Association (APIA) includes fauna removal only in 'sensitive areas' (i.e., national parks and nature reserves, or selected areas of native vegetation or wetlands). Such areas are typically identified by natural resource agencies and the proponents during the assessment phase prior to construction.

But what of the other 7353 individual animals, representing common or non-threatened species? Most of these animals were small (frogs, lizards, small snakes, and small mammals), weighing < 75 g body mass. Because small animals occupy small home ranges (Mace *et al.* 1983), many would have been unable to escape via the ramped trench plugs, which were usually positioned 500 m apart. Thus, we hypothesize that the majority of these small animals would not have survived without retrieval, due to their low mobility relative to the distance between trench plugs. Larger snakes and lizards, turtles, and larger mammals were less commonly trapped in the trenches. Although we would predict lower relative abundance of animals with larger body size (Blackburn and Gaston 1997), low captures of larger animals in the present study presumably also reflected frequent escape via the trench plugs, and numerous footprints in the plugs supported this.

Other pipelines have also incorporated an inter-plug distance of 500 m (A. Chapman, pers. comm., in Ayers and Wallace 1997), whereas earlier pipeline construction did not incorporate trench plugs (Moomba-Sydney trench, D. Ayers, pers. comm.). Woinarski *et al.* (2000) suggested that trench plugs be positioned at intervals of 200-500 m. However, it is likely that even trench plugs every 200 m would present small skinks with too great a distance to cover, given their low relative mobility. We foresee two options: position trench plugs every 50-100 m, or retrieve fauna on a daily basis. The former option is likely impractical and costly. The latter option, in combination with trench plugs every 400-500 m, would allow large animals to escape and entrapped smaller animals to be retrieved. It is worth noting that the consideration of whether to retrieve thousands of animals of non-threatened status from trenches in future pipelines is one of animal ethics or welfare, rather than one of only conservation concern. However, these unlisted species are protected wildlife, and it is generally illegal to directly harm or kill them knowingly or deliberately.

The effectiveness of opportunistic funnel trapping within the trench, particularly for frogs, indicates that this method is a worthwhile practice that augments fauna retrieval. The conventional use of these funnel traps is along drift fences with pitfall traps (Heyer *et al.* 1994), their main purpose being to capture animals too large or too agile to remain in pitfall traps. However, the pipeline trench provides an excellent opportunity to employ funnel traps: the trench, analogous to a fence, funnels animals into the traps. Advantages of funnel trapping are that large numbers of frogs or other animals can be captured overnight, and traps are relatively inexpensive to construct. Trapping, however, is labour-intensive (traps must be checked early in the morning to prevent desiccation and exposure), and we recommend opportunistic trapping when logistically feasible and within budget constraints.

We surveyed all open trenches every day during construction. Accordingly, observed mortality during pipeline construction was only 4 %. Fauna retrieval was explicitly incorporated into the Environmental Management Plan for the EGP (Duke Eastern Gas Pipeline 1999), and was originally to occur only in 'fauna management' areas, or 'sensitive areas' (e.g., Morton National Park) identified by NSWNPWS, DNRE, and the environmental consulting team prior to construction. However, the finding of significant numbers of fauna in open trenches early in the construction phase prompted an expansion of fauna retrieval to all open trenches, as volunteered by the proponent.

Despite the apparent success of our efforts, such measures are not currently federally mandated in Australia, despite an increase in pipeline construction in Australia (Woinarski *et al.* 2000). However, the APIA Code of Environmental Practice does recommend the management measures of fauna entrapment prevention, surveillance, and retrieval (pp. 4.1-14, APIA 1998), and these procedures have improved over the last decade. Thus, the pipeline industry in Australia has made considerable progress towards fauna protection during construction. It is suggested that the policies aimed at ameliorating the impacts of pipeline construction on fauna be reviewed, especially considering the low mortality and high number of rescues documented in this study as a result of fauna retrieval from the open trenches. Based on our findings, retrieving fauna from the entire trench would the most desirable outcome for animal conservation and ethics, and thus, the pipeline industry and the general community.

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References

APIA. 1998. Code of Environmental Practice. Australian Pipeline Industry Association, Canberra. (Section 4. Environmental Management Guidelines, Sub-section 4.1, Part A, Onshore pipeline Construction).

Ayers, D. and Wallace, G. 1997. Pipeline trenches: an under-utilised resource for finding fauna. Pp. 349-357 in *Conservation Outside Nature Reserves*, edited by P. Hale and D. Lamb. Centre for Conservation Biology, The University of Queensland, Brisbane.

Blackburn, T. M., and Gaston, K. J. 1997. A critical assessment of the form of the interspecific relationship between abundance and body size in animals. *Journal of Animal Ecology* **66**:233-249.

Burbidge, A. A. 1991. Cost constraints on surveys for nature conservation. Pp. 3-6 in *Nature Conservation: Cost Effective Biological Surveys and Data Analysis*, edited by C. R. Margules and M P. Austin. CSIRO: Australia.

Cogger, H. 2000. *Reptiles and Amphibians of Australia*. Reed: Sydney.

Dobson, A. P., Bradshaw, A. D., and Baker, A. J. M. 1997. Hopes for the future: Restoration ecology and conservation biology. *Science* **277**:515-522.

Duke Eastern Gas Pipeline. 1999. Environmental Management Plan. Duke Energy International and Ecos Consulting Pty. Ltd. Document No. 599-RP-006.

Faulkner, W. 1999. AGL Central West Project: Marsden-Dubbo gas pipeline. Fauna impact monitoring. Draft report to NSW National Parks and Wildlife Service and AGL.

Heyer, W. R., Donnelly, M. A., McDiarmid, R. W., Hayek, L. C., and Foster, M. S. 1994. *Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians*. Smithsonian Institution Press, Washington.

Mace, G. M., P. H. Harvey, and Clutton-Brock, T. H. 1983. Vertebrate home-range size and energetic requirements, Pp. 33-53 in *The Ecology of Animal Movement*, edited by I. R. Swingland and P. J. Greenwood. Clarendon Press, Oxford.

Simpson, K. and Day, N. 1999. *Field Guide to the Birds of Australia*. Penguin Books Ltd., Ringwood.

Strahan, R. (ed.) 1998. *The Mammals of Australia*. Reed New Holland, Sydney.

Woinarski, J. C. Z., Armstrong, M., Brennan, K., Connors, G., Milne, D., McKenzie, G., and Edwards, K. 2000. A different fauna?: Captures of vertebrates in a pipeline trench, compared with conventional survey techniques; and a consideration of mortality patterns in a pipeline trench. *Australian Zoologist* **31**:421-431.